MEASUREMENT OF PLANTAR PRESSURES, REARFOOT MOTION, AND TIBIAL SHOCK DURING RUNNING 10 KM ON A 400 M TRACK

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INTRODUCTION
Running style is likely to change as a consequence of fatigue. When does fatigue set in and what are the biomechanical changes that can be expected during distance running? The knowledge of changes in running behavior should have consequences for the construction of adequate footwear to protect runners from overuse injuries.

REVIEW AND THEORY
On a treadmill, Brüggemann et al. (1995) studied the effect of fatigue on peak vertical impact force and rearfoot motion of runners. The authors reported a decrease in impact peak force, changes in rearfoot kinematics and a decrease of the mean power frequency of the m. triceps surae during a 45 minute run on a treadmill. The authors concluded from their results that stiffness regulation is effected by fatigue. To study the changes of foot loading during fatigue, in-shoe plantar pressure measurements were performed for overground running.

PROCEDURES
Using a portable data acquisition system, 22 experienced male runners ran 10 km on a 400 m track in the same type of shoe (Nike Air Beckon). The runners were asked to run their best time for the given distance in order to observe effects of fatigue. A light weight Toshiba Laptop Computer (Libretto 100 CT) with a PCMCIA 12 bit A/D converter card was placed together with the electronic instrumentation in a back pack (total weight 2300 gram). Data collection was triggered at intervals of one minute for a duration of each 10 seconds at a rate of 1 kHz per channel. Rearfoot angle, tibial shock and plantar pressures were measured at the right leg of each subject. A pressure distribution unit Halm PD-16 (Halm GmbH, Frankfurt, Germany) with eight single piezoceramic transducers was used for the in-shoe pressure measurements. The transducers were positioned at palpated anatomical locations underneath the medial and lateral heel and midfoot, the metatarsal heads I, III and V, and the hallux. In a questionnaire the subjects reported that the transducers were barely felt under the foot during running. No subject had a feeling of discomfort during running, and they did not believe that the presence of the sensors influenced their running style. Simultaneously with the recording of the plantar pressures, acceleration measurements at the tibia were performed with a low weight Entran accelerometer (Type EGAX-F-25). As previously described, rearfoot motion was measured with an electrogoniometer (Milani, et al., 1995). Peak rearfoot motion, as evaluated in this study, refers to the total movement from the supination angle at ground contact to maximum pronation during stance. During a 10 second data collection interval between 12 and 15 ground contacts are collected. From the 12 to 15 repetitions mean values of the biomechanical parameters as well as intraindividual variability measures (Standard Deviation SD, Coefficient of Variability CoV) were calculated. Lap times were taken at 400 m intervals by the runners, using a wrist watch. The first 400 and the last 400 m were excluded from the analysis, to avoid influences on the data, possibly being caused by modified running styles during start and finish. Depending on performance level, the runners´ times varied between 30 and 50 minutes for the 10 km distance. For normalization purposes, the total running time of each individual was divided into 5 equal intervals, and averages of the biomechanical variables were calculated.

RESULTS & DISCUSSION
Only a small but significant reduction (p<0.01) in running speed was found from the first (3.7 m/s) to the second half (3.6 m/s) of the 10 km distance. From the first to the last of the five distance intervals, stride cycle time increased from 700 to 712 ms (p<0.01) and ground contact time by approximately 3% from 247 to 254ms (p<0.01). Table 1 summarizes the parameter means from the first (400 m – 2240 m) to the last interval (7760 m -9600 m).
Table 1: Peak pressures (in kPa) under the lateral & medial heel and midfoot (P-L/MH; P-L/MMF), the metatarsal heads V, III, I and the hallux (P-M-V/III/I; P-Hallux); peak acceleration in g (P-ACC) and peak range of rearfoot motion in degrees (PROM) (* p<0.05, ** p<0.01).

<table>
<thead>
<tr>
<th></th>
<th>P-LH</th>
<th>P-MH</th>
<th>P-LMF</th>
<th>P-MMF</th>
<th>P-M-V</th>
<th>P-M-III</th>
<th>P-M-I</th>
<th>P-Hallux</th>
<th>P-ACC</th>
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<tr>
<td>INT 1</td>
<td>611</td>
<td>634</td>
<td>201</td>
<td>218</td>
<td>346</td>
<td>690</td>
<td>947</td>
<td>433</td>
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<td>16.0</td>
</tr>
<tr>
<td>INT V</td>
<td>546 **</td>
<td>586 **</td>
<td>186 **</td>
<td>175 **</td>
<td>328 *</td>
<td>635 **</td>
<td>850 *</td>
<td>370 **</td>
<td>8.3</td>
<td>15.7</td>
</tr>
</tbody>
</table>

At the end of the 10 km run the peak pressures are substantially lower as compared to the first 2000 m. Peak acceleration is slightly reduced and there is no change in the total range of rearfoot motion or maximum pronation velocity (652 °/s, Int-1 vs. 623 °/s, Int-V). Although only a minor change in running speed was found throughout the 10 km distance, peak pressures showed reduced values from the beginning to the end of the run. The changes were biggest from interval 1 to interval 2, as it can be seen in figure 1.

The early change indicates that it is probably not caused by fatigue but occurs as a consequence of modifications in footwear properties. It is known that the temperature inside of a running shoe increases with the duration of running. This temperature change and the mechanical use of the shoe may cause a softening of the midsole material. Relative load analyses are independent of changes of material properties with time, because they relate the force-time integral from one anatomical area to the summed integral of all other anatomical areas. Therefore, a relative load analysis was performed to investigate if runners use different foot loading strategies in the later course of a run. Figure 2 shows the changes in relative loads between the first and second half of the total running distance. During the second half of their run the subjects demonstrated increased loading of the rearfoot and the lateral portion of the mid- and forefoot, unloading the medial midfoot and the first ray (1st metatarsal bone and hallux). Less involvement of the first ray may be the consequence of fatigue, because the first ray is one of the primary structures during push-off in locomotor activities. The tendency of a more lateral loading pattern may also explain why the peak range of rearfoot motion did not increase towards the end of the run, although the midsole material became softer with time.

REFERENCES

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